Feature Article

Self-dependent Mini Mills

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ABSTRACT

All the mills in Malaysia were set up to serve plantations that are fairly large and can produce sufficient crop for a mill capable of processing at least 20 t hr^{-1}. This processing capacity would produce sufficient fuel for generating the required heat and power for the mill and as such may be termed an optimum sized self-supporting palm oil mill. Unfortunately, these mills used boilers and steam turbines that were custom-made to operate with minimum efficiency to address the issue of costly biomass disposal by burning it as a fuel in boilers. These boilers also doubled up as incinerators to burn away the surplus biomass. Unfortunately, nothing was done to find out the capacity of the smallest self-supporting mill. A new focus would invariably uncover new research areas where emphasis will be focused on maximum fuel efficiency and minimum waste. This article explores all the areas that would contribute in one way or other towards the development of the smallest self-supporting mini mill that can serve small plantations operating in isolation.

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INTRODUCTION

In 2012, Malaysia produced 18.79 million tonnes of crude palm oil (CPO) with an export revenue valued at RM 71.40 billion. Oil palm planted areas in 2012 totalled 5.08 million hectares and the fresh fruit bunches produced were processed by 425 mills in operation, is as shown in *Table 1* (MPOB, 2013).

In order to increase the CPO production, intensive effort has been focused on palm oil mills to have a better extraction rate of the oil, as highlighted in Entry Point Projects (EPP) 4 thus aiming to increase national oil extraction rate (OER) to 23% by year 2020. Oil losses survey on pressed fibres, steriliser condensate, sludge and empty fruit bunches show that palm oil mills presently need to develop a new sustainable process involving process integration of ecosphere, raw material logistics and stakeholders outside the industry rather than process optimisation (Michael Narodoslawsky, 2007).

THE EARLY FOCUS OF THE INDUSTRY

A survey of the Malaysian palm oil industry shows that as oil palm cultivation increased, mill capacities gradually grew from 10 t

TABLE 1. MALAYSIA: OIL PALM PLANTED AREA AND MILLS CAPACITY IN YEAR 2012

State	Mature (ha)	Immature (ha)	Total (ha)	Mills	t FFB yr^{-1}
Johor	618 353	95 777	714 130	67	17 053 600
Kedah	76 181	8 342	84 523	7	1 660 000
Kelantan	91 182	46 497	137 679	12	2 039 200
Melaka	48 718	3 806	52 524	3	636 000
Negeri Sembilan	143 580	23 496	167 076	15	3 389 400
Pahang	595 799	104 402	700 201	72	15 440 200
Perak	338 100	41 846	379 946	47	10 500 800
Perlis	197	87	284	0	0
Pulau Pinang	13 264	292	13 556	2	294 000
Selangor	124 080	12 611	136 691	22	3 925 600
Terengganu	136 509	34 984	171 493	14	3 347600
Sabah	1 292 757	149 831	1 442 588	133	33 163 200
Sarawak	874 152	202 086	1 076 238	65	13 974 000

hr^{-1} to 20 t, 30 t, 45 t, 60 t, 80 t, 90 t and even 120 t. Small plantations always had to be closely located to the existing mills that were generally big. These mills catered for a large input of crop that often exceeded 400 t per day and for which the mill needed a processing capacity of at least 20 t hr^{-1}. This discouraged the development of small scale plantations in isolated regions that were far away from any large mills. The industry has failed to look into the possibility of establishing small plantations in the small settlements that are widely scattered in many villages where, the land has not been fully exploited for generating farm products that could increase the income of the people in villages. There is only one obstacle that has stood in the way and that was the conspicuous absence of self-dependent mini mills. Not much however has been done to probe this area although there is great potential to grow oil palm in remote areas in Malaysia, which could even total one million hectares.

The early mills, even until recently, had to perform the now unpleasant task of destroying the surplus biomass generated by the mill. This was necessary because the accumulation of the biomass could seriously obstruct the mill operation unless the mill could clear it by either selling it or burning. In the absence of a strong market demand for the biomass, biomass burning or incineration was adopted as the best solution at that point in time. The boilers also had to be inefficient as a means of reducing the biomass accumulation in mills. The turbines were designed for high specific steam consumption as additional power produced could not be sold as there were no electricity consumers in the neighbourhood.

PARADIGM SHIFT

In the last decade however, the scenario took a welcome turn to combat the adverse environmental issues caused by dangerous pollutants and greenhouse gases that lead to climate change and global warming. With that, the interest in green energy made its debut on a global level largely promoted by the escalating cost of conventional fossil fuel. In this respect, Europe particularly Denmark, made great strides in the development of green or renewable energy.

With a new approach, towards global warning issues, a different look at the optimum size of a mill that would be self-supporting in terms of fuel dependency

became necessary as the parameters in the equation for sustainable energy production had also changed when fuel efficiency became the focal point. Self-dependency in this case refers to the electricity utilised that has to be generated by the mill itself without depending on imported electricity from national service provider or other sources.

For becoming self-supportive the power generation equipment is also needed to undergo many technical changes to improve efficiency. The untapped resources are targeted for use as a resource material that can provide the fuel for power generation thereby increasing the income of the organisation.

In the following analysis, the empty fruit bunch will also be considered as regular fuel unlike conventional mills, which relied only on monocarp fibre and kernel shell as fuel. In this analysis, we have arbitrarily selected the size of the mill and studied its mass and energy balance so that we could narrow down the optimum size by inter or extrapolation. The various biomass components are represented as ratios to the fresh fruit bunches processed are shown in *Table 2* (Ravi *et al*., 2003).

A 5 t hr^{-1} mill has been used for calculating biomass produced its heat generated as shown in *Table 3*.

TABLE 2. BIOMASS COMPONENTS AND PRODUCTION RATE

Biomass components	Production rate
Empty fruit bunches	23% to fresh fruit bunches
Mesocarp fibre	13% to fresh fruit bunches
Kernel shell	6% to fresh fruit bunches
Palm oil mill effluent (POME)	65% to fresh fruit bunches
Biogas	24 m^3 t^{-1} of POME at 34°C, 1 atmosphere

TABLE 3. MASS AND HEAT OF THE BIOMASS FROM A 5 t hr^{-1} PALM OIL MILL

Biomass	Wet quantity (t hr^{-1})	Moisture (%)	Calorific value (kJ kg^{-1})	Net energy (kJ)
Empty fruit bunch*	1.15	70	(dry) 18 795 (wet) 5 638	6 483 700
Mesocarp fibre*	0.65	40	(dry) 19 055 (wet) 11 433	7 431 450
Kernel shell*	0.30	10	(dry) 20 093 (wet) 18 084	5 425 200
Total biomass	2.10			19 340 350
Effluent	3.25 t hr^{-1}			
# Biogas (ideal gas) $V_2 = \frac{273V_1}{(273+34)}$	$V_1 = 78$ m^3 $V_2 = 69.36$ m^3		22 860 kJ m^{-3}	1 585 605 kJ
Grand total				20 925 955 kJ

Note: *The calorific values of empty fruit bunch, mesocarp fibre and kernel shell were taken from analysis conducted by Vijaya *et al*. (2004).
#The calorific value of biogas was obtained from Ma (1999).

With Biogas Tapping

Total usable energy from the biomass of a 5 t hr^{-1} palm oil mill = 20 925 955 kJ (1)

Assuming a boiler efficiency of 80% when converting water to steam.

Heat available for conversion to steam = 20 925 955 x 70% = 14 648 168 kJ (2)

Heat required to evaporate 1 kg water at 217°C to steam at 22 bar_g, h_{fg} = 1880 kJ (3)

Heat required raising the temperature of feed water from 34°C to 217°C is

$C_p\theta$ = 4.2 x (217-34) = 4.2 x 183 = 769 kJ (4)

where C_p is the water specific heat capacity. Thus, total heat required to raise 1 kg of boiler feed water from 34°C to 217°C and evaporate it to saturated steam is (Mayhew, 1974):

1880 + 769 = 2649 kJ kg^{-1} (5)

Steam that could be generated with the available fuel = 14 648 168/2649 = 5.53 t hr^{-1}. A mill usually requires a minimum boiler capacity of 65% of the mill capacity, thus

The minimum boiler capacity = 5 x 65% = 3.25 t hr^{-1} (6)

Without Biogas Tapping

From *Table 3*, the total energy available from the biomass excluding biogas is 19 340 350 kJ. Assuming a conservative boiler efficiency at 70%, available energy for steam generation is:

19 340 350 x 70% = 13 538 245 kJ (7)

From Equation (5), 2649 kJ of energy needed for converting 1 kg of boiler feed water at 34°C to saturated steam at 22 bar, thus amount of steam could be generated is:

13 538 245/2649 = 5111 kg ≈ 5.1 t hr^{-1} (8)

Therefore, a 5 t hr^{-1} boiler will be more than adequate for the 5 t hr^{-1} palm oil mill. The boiler will be able to supply steam without emitting black smoke as it will not be running at full capacity.

The power requirement of a mill may be calculated based on the unit consumption that varies from about 17 to 20 kW t^{-1} of fresh fruit bunches processed. For the present computation, a conservative approach has been adopted.

Power requirement of a 5 t hr^{-1} palm oil mill = 5 x 20 = 100 kW (9)

Steam Turbine or Steam Engine

The steam turbo-alternators seldom come at a capacity of 100 kW but it is possible to manufacture such units if there is sufficient demand for it. On the other hand, steam engines of this size having higher efficiencies are easily available. One such machine is 'Spilling' steam engine. By assuming the steam consumption for the isentropic expansion and electrical energy conversion to be 30 kg per kWhr, and with a input steam of 5100 kg the electrical energy generated is the equation as shown below:

Electrical energy generated = $\frac{5100}{30}$ = 170 kW (10)

Energy check:

The input energy to the turbine is 13 538 245 kJ as calculated in Equation (7). From the steam table (*Figure 1*), the work done in Rankine cycle is H_{g1} - H_{g2} = 2801 - 2739 = 62 kJ and available energy is H_{g1} - H_{f2} = 2801 – 584 = 2217 kJ (Mayhew and Roger, 1984). Thus, the fraction used for power generation is 62/2217 = 2.79% say 2.7% as a conservative figure. The electrical energy output is:

13 538 245 x 2.7% = 365 532 kJ → Power output = $\frac{365\,532}{3600}$ = 101.54 kW (satisfactory) (11)

Based on *Tables 2* and *3*, data for different mill capacities were derived as shown in *Table 4* to enable extrapolation or interpolation to derive appropriate values as shown in *Figures 2* and *3*.

DISCUSSION AND CONCLUSION

Process sustainability has been evaluated based on three aspects consisting of human society, environmental impact and economic growth. The palm oil industry has brought significant revenue to the nation and has provided a livelihood to millions of people. Recently, the environmentalists and the government have been urging the industry to preserve not only the quality of the environment but also to ensure the natural environmental balance of the eco systems.

Palm oil mills with certain capacities have been built at various strategic locations so that harvested fresh fruit bunches can be transported from nearby estates and plantations. In 2012, Malaysia's average fresh fruit bunches yield was 18.89 t^{-1} ha^{-1} yr^{-1} and average oil extraction rate was 20.35% (MPOB, 2013). Thus, fossil diesel had to be burnt to haul the load with only 20.35% useful resources all the way to the processing mill. Life cycle analysis shows that transport logistics contribute significant carbon footprints and become a shaping factor for process structures in the future. This phenomenon shows that the determination of the right size and geographical distribution are crucial issues to be considered.

A new approach proposes that all the harvested fresh fruit bunches have to be processed in a local mini mill powered by renewable resources so that only loose palm fruitlets will be transported to nearby mills for further processing. Based on the data shown in *Table 2*, this approach will increase the oil extraction rate to 26% and

TABLE 4. POWER REQUIREMENTS AND POWER PRODUCTION CAPACITY OF SELF-SUPPORTING MILLS

Mill capacity (t hr^{-1})	**1**	**2**	**5**	**7**	**8**	**10**
Empty fruit bunch (kg)	230	460	1 150	1 610	1 840	2 300
Net energy (kJ)	1 296 740	2 593 480	6 483 700	9 077 180	10 373 920	12 967 400
Mesocarp fibre (kg)	130	260	650	910	1 040	1 300
Net energy (kJ)	1 486 290	2 972 580	7 431 450	10 404 030	11 890 320	14 862 900
Kernel shell (kg)	60	120	300	420	480	600
Nett energy (kJ)	1 085 040	2 170 080	5 425 200	7 595 280	8 680 320	10 850 400
Biomass energy (kJ)	3 868070	7 736 140	19 340 350	27 076 490	30 944 560	38 680 700
Effluent volume (t)	0.65	1.30	3.25	4.55	5.20	6.50
Biogas volume (m^3)	15.60	31.20	78.00	109.20	124.80	156.00
Sea level volume (m^3)	13.87	27.74	69.36	97.11	110.98	138.72
Biogas energy (kJ)	317 121	634 242	1 585 605	2 219 847	2 536 969	3 171 211
Total energy (kJ)	4 185 191	8 370 382	20 925 955	29 296 337	33 481 529	41 851 911
Power requirement (kW)	20	40	100	140	160	200
Rankine efficiency (%)	2.7	2.7	2.7	2.7	2.7	2.7
Without biogas (kW)	29	58	145	203	232	290
With biogas (kW)	31	63	157	220	251	314

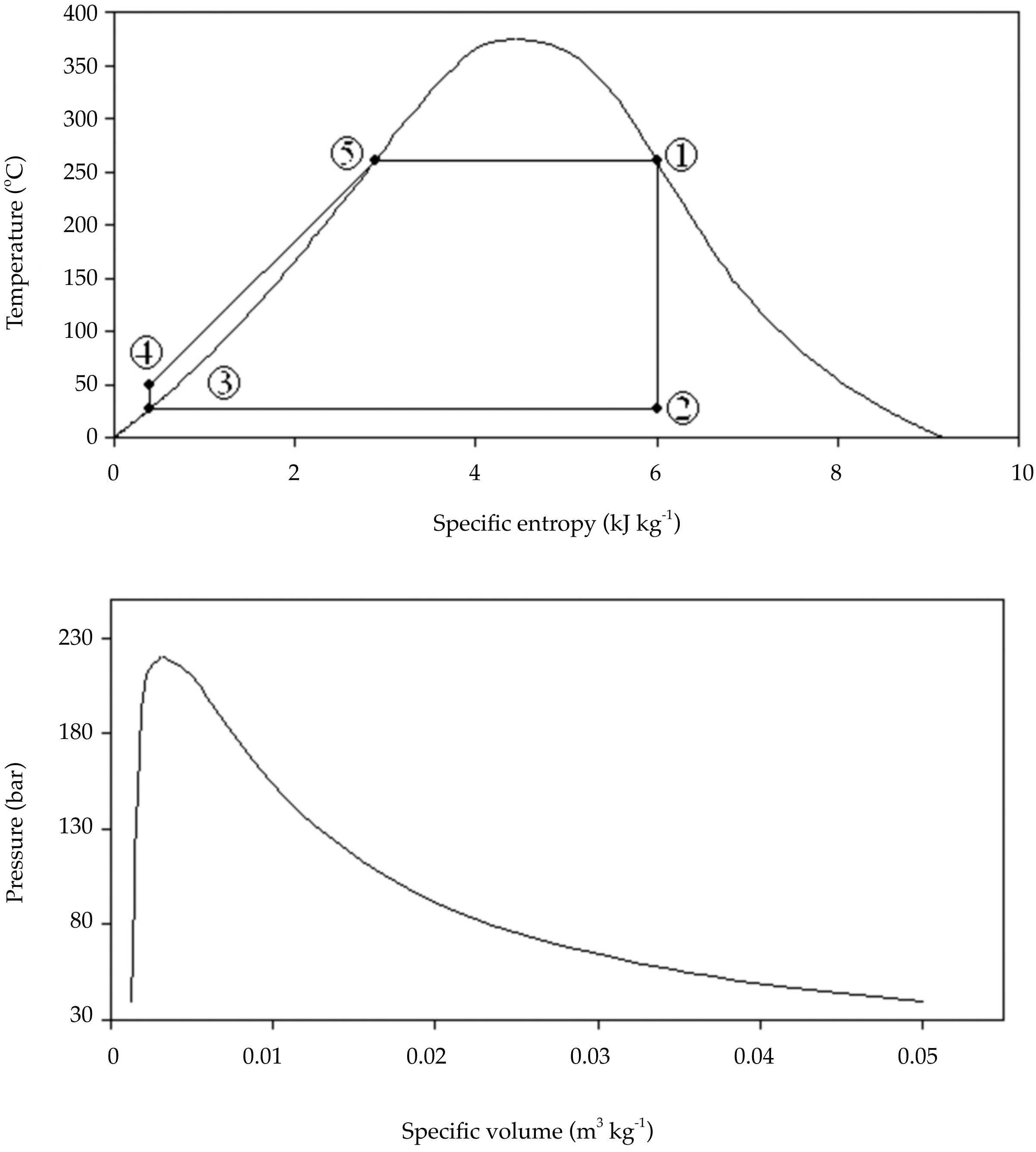

Figure 1. Rankine cycle with t-s and p-v charts for steam.

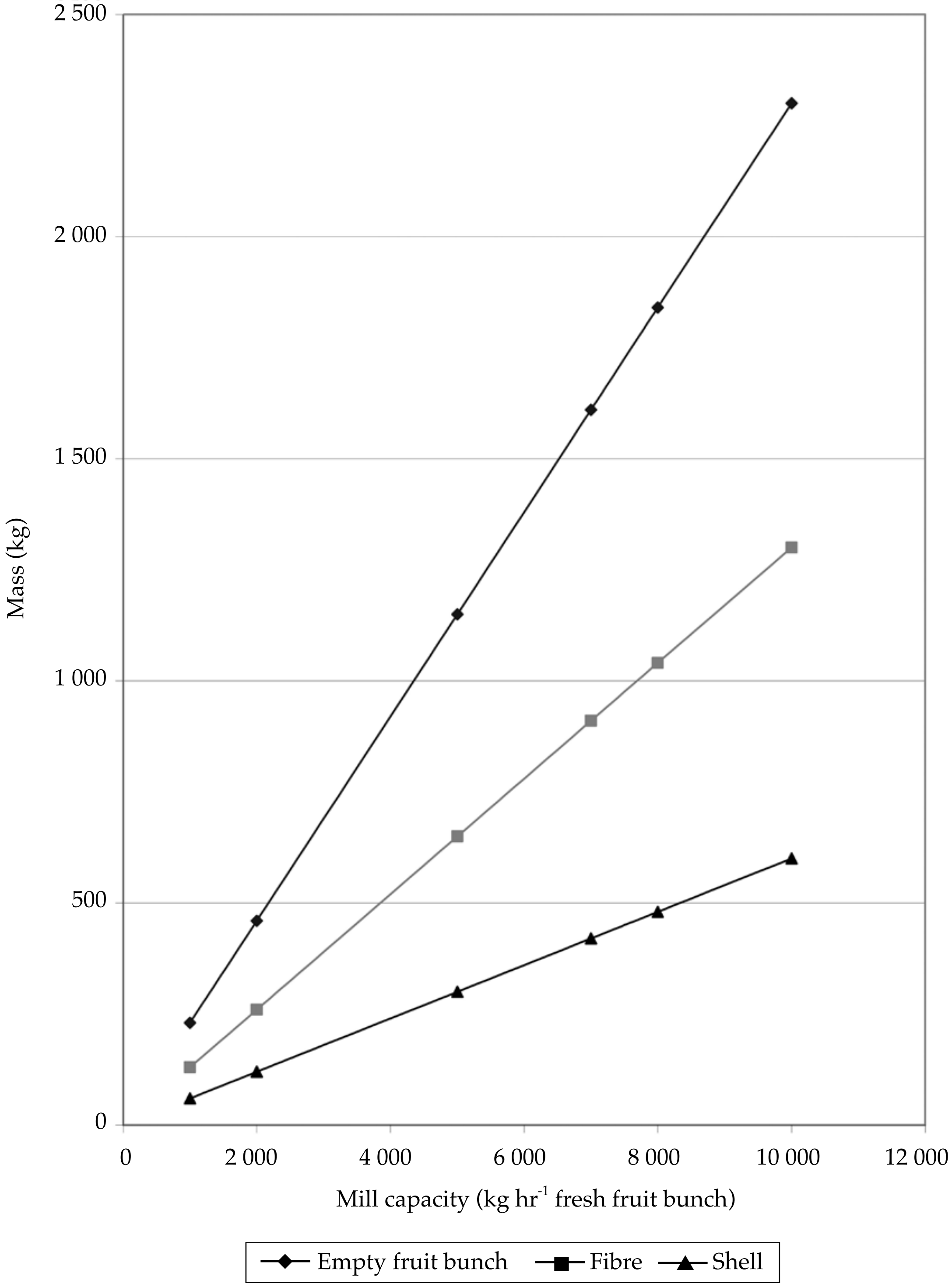

Figure 2. Palm oil mill biomass production.

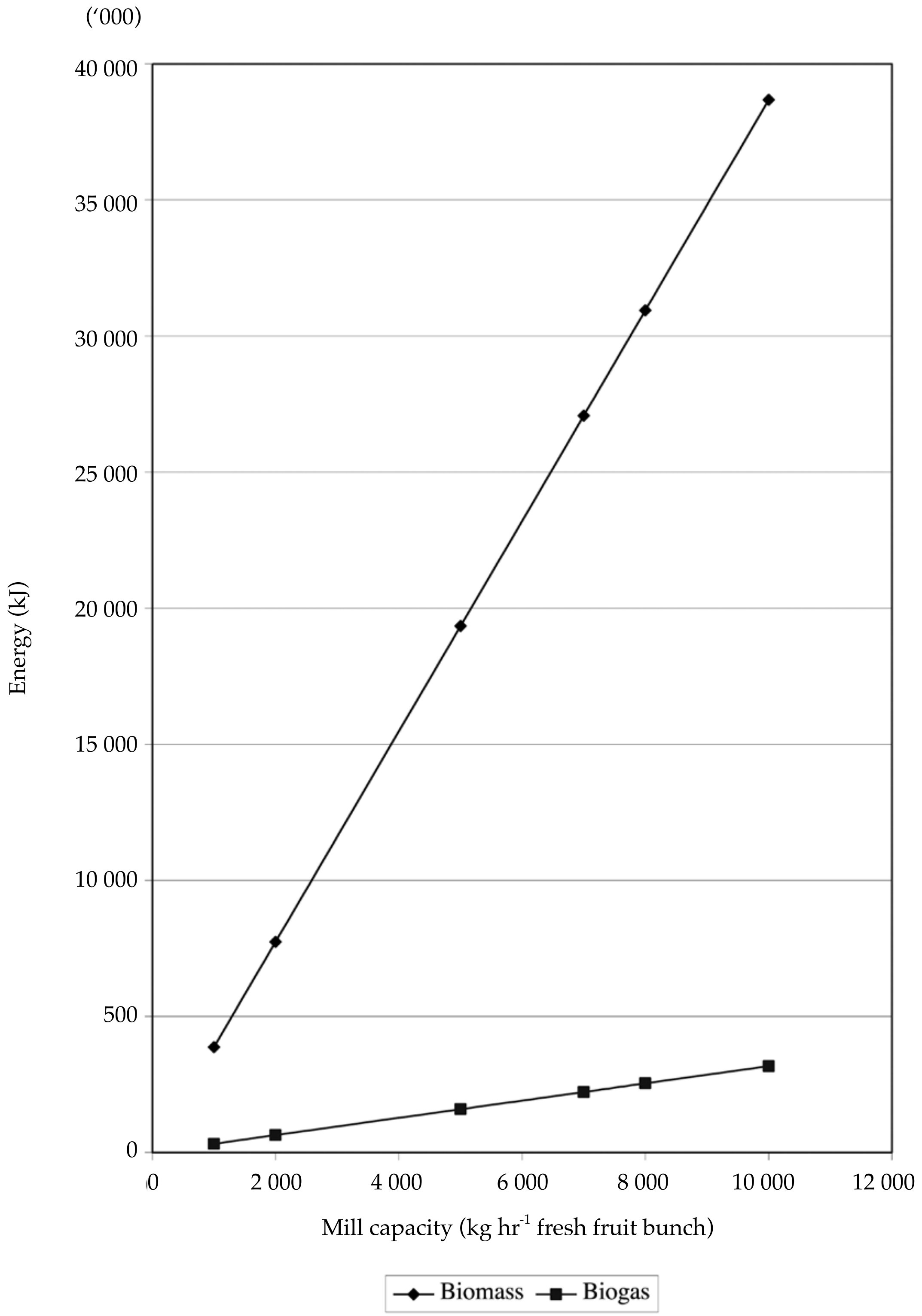

Figure 3. Palm oil mill energy production.

all the empty fruit bunches can be utilised as fertiliser in the local estate without any long distance transportation thus further reducing the carbon footprints in the life cycle analysis.

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